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ViNEL: A Virtual Networking Lab for Cyber Defense Education

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Abstract

Professors teaching cyber security classes often face challenges when developing workshops for their students: How does one quickly and efficiently configure and deploy an operating system for a temporary learning/testing environment? Faculty teaching these classes spend countless hours installing, configuring and deploying multiple system configurations only to decommission the operating system after needed usage is complete. This paper presents a system that was developed to significantly reduce testing environment setup times by establishing a virtual networking lab (ViNeL) that allowed a cyber defense club at a public regional university to spin up an entire network of virtual machines to simulate business environments and prepare for competitions. The application also allowed club members to launch a single operating system for lab style experimentation. The application uses the remote desktop protocol (RDP) to make it platform independent. Built using Oracle VirtualBox on a LAMP stack (Linux, Apache, MySQL, and PHP), the virtual networking lab is completely open source and can be implemented on a variety of server hardware configurations. Details on the development and implementation are presented to aid in the development of similar systems in different environments.

Keywords: Cyber Security, virtual environments, curriculum, building systems.

1. INTRODUCTION

Professors teaching cyber security classes often face challenges when developing classes for students: How does one quickly configure and deploy an operating system for a temporary testing environment and store the configuration for later use? As is the case with most enterprise level system administrators, most instructors spend countless hours installing, configuring and deploying multiple system configurations.

However, unlike system administrators, the configurations are used for lab exercises and practice sessions. Then they destroy the lab OS configurations after the needed usage is complete to make room for the next lab activity and subsequent setup.

ViNeL was created to provide a Virtual Networking Lab to allow cyber defense club members and team competitors' constant availability to operating systems and configurations used in

workshops and practices without the need to rebuild OS configurations from scratch. Using a private cloud infrastructure, the application also decreased the configuration deployment time from an average of 5 hours to 30 minutes; a reduction of 90%. This same technology could be applied to classroom environments in different areas.

This paper will explain the setup used by the cyber defense club at a public regional university, highlighting the challenges the club faces with lab configuration. This is followed by a review of possible technologies that can be used to create such a proposed networking lab. After detailing the implementation solution, the results of the implementation are reviewed. Lastly, we discuss the implementation of such structures for testing and development.

2. PROBLEM CONTEXT

In this section we outline the typical setup process used by the cyber defense club and highlight any requirements for the new system in order to address the challenges faced in the lab and operating system setup process.

CYBER DEFENSE CLUB Setup Processes

Since the CYBER DEFENSE CLUB is comprised of a club members and a competition team, each segment of the CYBER DEFENSE CLUB has specific needs for system setups.

Club: Lab Use

The CYBER DEFENSE CLUB holds workshops every 1-2 weeks. These workshops use multiple configurations across various operating systems that get used from year-to-year. However, there is currently no organization in the archival of such configurations. Thus, lab configurations are implemented from scratch for each use. The following setup process is used by club officers to setup computers for workshops and labs.

1. Installation – The operating system is downloaded or retrieved from a network storage device and installed on the master machine. This master can either be a virtual machine or a physical computer. Each operating system is installed from an online repository which uses a minimal copy of the operating system. The time of installation was increased as most of the installation files will have to be downloaded at the time of installation. However, all current versions of packages are installed and no updates will need be applied during the next phase of setup. This method is advantageous for workshop

configurations that need updated software for practicum. (Timeframe: 15 – 60 minutes)

2. Configuration – Each system is configured for the needed services required by competition practice or workshops. New applications are installed and tested to ensure execution of lab steps. (Timeframe: 1 – 5 hours)

3. Distribution – Once the master machine has been properly configured, the image is distributed using one of the following methods. (Timeframe: 1 – 8 hours)

a. VirtualBox + Dropbox – If the installation was created on a virtual machine, the entire VM is exported in the Open Virtualization Format (OVF) via Oracle VirtualBox (Oracle VM Virtualbox, 2015) and added to the CYBER DEFENSE CLUB Dropbox. This method was preferred as the local installation of Dropbox on each member machine automatically downloads an offline copy of the VM that can later be imported into VirtualBox. However, Dropbox has a storage limit and as such this method is typically used for smaller VMs.

b. Clonezilla – If the installation master is created on a physical machine, an image file is created using the disk imaging tool Clonezilla and stored to the CYBER DEFENSE CLUB network attached storage device. The master is then physically cloned to each machine using the Clonezilla interface. This method is used for VMs that are too large to upload to Dropbox. However, it is not preferred as all previous configurations on the client machine are erased.

A summary of the lab use setup is shown in **Figure 1** (Contained in the appendix).

Team: Competition Practice Use

The CYBER DEFENSE CLUB competition team competes in the Southeast Collegiate Cyber Defense Competition (SECCDC). Each year, the SECCDC releases two network topologies used in competition (SECCDC, 2015). Competition topologies contain 5 – 8 networked machines each. The CYBER DEFENSE CLUB creates an in-house copy of these topologies on which to practice throughout the competition season. These systems were created on physical machines and erased at the end of each season. The following setup process for each machine is used by competition team members for competition practice.

1. Installation – The operating system is downloaded or retrieved from a network storage device and installed from a full installation disc which uses full copy of an operating system saved to disk as the source of installation. Due to teams being responsible for updating and patching their

systems during competition, this method is more convenient for competition network setups. (Timeframe: 15 – 60 minutes per machine)

2. Update – Once properly configured to access the internet, the operating system is patched and updated to the latest available versions by the team member responsible for that OS. (Timeframe: 1 – 5 hours per machine)

3. Configuration – Once updates have been applied, each system is configured for the needed services need for competition practice or workshops. (Timeframe: 1 – 5 hours per machine)

4. Networking – Once the network domain is properly configured, the networking configuration is applied to each system. (Timeframe: 5 – 30 minutes per machine)

A summary of the competition practice setup is shown in **Figure 2** (in the Appendix).

Requirements

The purpose of this project is to find a solution or build an application to ease the lab setup process for the CYBER DEFENSE CLUB and its team. Due to the differences in lab and practice setups, the OS deployment application system will need to be developed into two major components: single instance use for club workshops and network use for competition practice. Each of the requirements outlined below will describe the necessary capabilities for each situation.

1. Performance – Each user will need to access his/her own virtual machine that meets the minimum system requirements outlined for the operating system in use.

a. Club workshops: The CYBER DEFENSE CLUB has an average attendance of 15 members per week. The application must be able to support up to enough machines to allow each attending member to run a VM simultaneously. Lab-based setups do not currently require more than 1 CPU core. (Minimum: 30 GB of RAM, 1 CPU Core)

b. Competition Practice: Competition topologies use an average of 7 servers per competition. The application must be able to support the running of all VMs configured in the network topology simultaneously. The requirements assume that only one topology is deployed at a time. Some virtual machine require the use of multiple cores. (Minimum: 20 GB of RAM, 2 CPU Cores)

The hardware used for the application will need to have a minimum of 2 cores and 30 GB of RAM.

2. Self-Service – The application will need to allow users to quickly deploy and control their own virtual machines and networks without the need for administrative assistance or manual installation. Each user will need their own account to ensure access control for each running VM instance.

3. Platform Independent – Members of the CYBER DEFENSE CLUB use Windows, Mac and Linux systems for personal use. Allowing users to access VMs from personal laptops will reduce the amount of hardware needed to serve as client machines for the club. The application must be able to be run from multiple platforms, most notably Windows, Mac, and Linux operating systems.

4. Networking – For the competition team, practice servers are configured in a network provided by the SECCDC. Virtual machines within the application will need to have the ability to be networked in small, isolated, and non-conflicting networks for competition practice use.

5. Affordable – The CYBER DEFENSE CLUB has a limited budget. To avoid paying for licenses and additional hardware, the implementation cost of the application needs to be minimal. If possible, software used should have free or open source licenses.

3. CLOUD COMPUTING PLATFORMS

This chapter will review possible software solutions based on the requirements for the CYBER DEFENSE CLUB. Each product was reviewed and analyzed to determine the most suitable solution for the storage of system configurations and fast, on-demand access of those stored configurations.

Infrastructure as a Service

According to the National Institute of Standards and Technology (NIST), Infrastructure as a Service is defined as:

“The capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications.” (Mell & Grance, 2011)

Of the service models listed in the NIST publication defining cloud computing, the Infrastructure as a Service (IaaS) model aligned best with the needs of the club. IaaS encapsulates the self-service requirement for the CYBER DEFENSE CLUB virtual networking lab application

and will serve as the model of service provided to the club.

Infrastructure as a Service Provider Reviews

Three IaaS providers are reviewed below. A brief overview of each is given, as well as a synopsis of how they can be used as a solution for virtual networking with the CYBER DEFENSE CLUB.

Amazon Elastic Compute Cloud

Amazon Elastic Compute Cloud (EC2) is web-based service that allows users to create virtual hosts in the cloud (Amazon EC2, 2014). Features of EC2 include:

- Pre-configured templates for deployment called Amazon Machine Images (AMI)
- Configurable network and security settings
- Management tools for VM control
- Ability to run instances in multiple locations called Availability Zones
- Pay-per-hour billing

Amazon EC2 has the ability to allow each CYBER DEFENSE CLUB user to create and manage their own virtual servers, save configurations, and re-deploy as needed. The competition team can also manage their own machines, while configuring the networking and security settings to mimic those of the SECCDC network topologies.

Microsoft Azure Virtual Machines

Microsoft Azure Virtual Machines (Virtual Machines, 2015) lets users deploy various computer configurations instantly. Features of Microsoft Azure Virtual Machines include:

- Scaling up to 1000 instances
- Virtual networking and load balancing
- Ability to transfer machines between Hyper-V and Azure
- Pay-per-minute pricing

Microsoft Azure Virtual Machines could allow the CYBER DEFENSE CLUB to create in-house images that can be uploaded to Azure for instant distribution via the Azure Virtual Network. The Azure Virtual Network can also be used to create copies of the SECCDC topologies for practice sessions.

Apache Virtual Computer Lab

Apache Virtual Computer Lab (VCL) is an open-source cloud computing platform that allows users to deploy custom computing environments (The Apache Software Foundation, 2015). Features of Apache VCL are listed below:

- Free and open source
- Ability to schedule the usage of VM instances
- Image revision control
- Provides user access control models

- Supports the use of multiple provisioning methods

Apache VCL can allow the CYBER DEFENSE CLUB to launch images based on member roles. Team members could have separate access to particular VMs to which regular club members to do not have access.

Infrastructure as a Service Provider Analysis

Each service provider was rated on how well they could meet the requirements needed for a virtual networking lab. The summary of their ratings are shown in Figure 3 (contained in the appendix).

Performance

Amazon EC2 and Microsoft Azure VMs both provided cloud-based virtual machines that could provide performance at nearly any level; however, the better the performance of the virtual machine, the higher the cost. The Apache VCL platform must be installed on your own hardware, so the performance depends upon the available resources of the user. VCL is limited to hardware capabilities on-hand, whereas EC2 and Azure VMs can be scaled elastically to meet dynamic needs.

Self-Service

Each provider allowed the user to log into an account from which they could launch and control virtual machines in a self-sufficient manner. Apache VCL trailed slightly behind due to the fact that it does not offer nearly as many features as EC2 or Azure VMs. However, not all of the additional features provided by those two IaaS platforms are necessary to meet the requirements of the CYBER DEFENSE CLUB.

Platform Independent

All platforms provided access to the virtual machines via Secure Shell protocol (SSH) or Remote Desktop Protocol (RDP), which allows access from Windows, Linux or Mac. These protocols also allow for mobile to be used for connection provided the mobile device application store includes SSH and RDP mobile applications.

Networking

Microsoft Azure VMs provided the most configurable and user-friendly networking design of the three platforms. Apache VCL did not provide a networking feature capable for use by the competition team. While there was a clustering feature which could be used for lab configurations, there was no way to network two VM instances running different operating systems in Apache VCL.

Affordable

While Apache VCL is free and open source, the Amazon and Microsoft pricing model calculated charges for per hour that the virtual machine was running. Costs were also accumulated for the storage of virtual machine images. Table 1 shows the cost of using cloud-based virtual machines for both the club member and team competitors (shown in the appendix). It is assumed that virtual machines are powered off when not in use.

Solution Selection

Based on the rating scale, Microsoft Azure VMs scored best on average for the CYBER DEFENSE CLUB requirements. Apache VCL could not be used due to the lack of networking capability. Amazon Web Services only provided a core set of servers at the above prices. Customized or unconventional operating systems incurred an additional cost.

While the cost of using Microsoft Azure VMs is reasonable, it was noted in the pricing plan that operating systems licensing fees were included in the cost. Through the Microsoft Imagine Subscription (previously Microsoft DreamSpark) purchased by the university, the CYBER DEFENSE CLUB already has free licenses to several Microsoft operating systems and software, as long as the software is installed on servers and computers located on campus (Microsoft DreamSpark Premium Subscription Agreement, 2015). This is common on campuses, as Microsoft offers this service to campuses at a very reasonable cost.

Instead of paying for licenses already freely available to students, it is feasible to create a custom platform similar to Amazon EC2, Microsoft Azure VMs and Apache VCL that meet all needs of the CYBER DEFENSE CLUB without any additional purchases.

4. IMPLEMENTATION

The custom virtual networking lab platform (ViNeL) was designed to meet all of the requirements of the CYBER DEFENSE CLUB. The system was installed using a LAMP stack (Linux, Apache, MySQL, PHP) and will allow club officers to upload configured VMs to the server to be stored and made available to use. Club members were able to launch up to one VM instance at a time. Competition team trainers can upload configured VMs used in SECCDC topologies and provide IP address details for the system to use to network the machines together. The method of implementation is detailed below. The ViNeL

architectural diagram is shown in Appendix A as figure 4.

Hardware Specifications

ViNeL was installed on a Sun Microsystems Sun Fire X4150 Blade Server. The system specifications are listed in table 2 (in the appendix).

This particular server was used as it was currently available for use for the CYBER DEFENSE CLUB. However, the application can be installed on any server hardware with at least 4 CPU cores and 15 GB of RAM.

Operating System

Ubuntu Server 14.04 LTS (64-Bit) was installed on a 30 GB root partition. The rest of the hard drive space was configured to support a logical volume manager (LVM). The installation used a network installation disc with the Basic Ubuntu Server, LAMP Server, OpenSSH Server packages selected to be installed initially. The server was configured to install security updates automatically.

Web Server

The most current release of Apache HTTP server (as of writing: 2.2.29) was installed on the server. The website design was based on the Twitter Bootstrap Dashboard template (Bootstrap Core Team, 2015) and used Chart.js (Downie, 2015) to display charts of system information. Plupload (Moxiecode Systems AB, 2015) was used to upload VM images to the server by chunking the files to allow uploads to be paused and resumed. The webserver uses PHP and JQuery for website scripting. The HTTP servers were hardened using the "Security hardening on Ubuntu Server 14.04" guide (Brock, 2014).

Database

The Ubuntu MySQL server package (as of writing: 5.5) was installed on the server blade. A database was created to store user, group, and VM data. The webservers use the PDO class in PHP to establish connections with the database and execute queries. The database design for ViNeL is presented in the Appendix as figure 5.

VM Hypervisor

The server has the most current version of Oracle VM VirtualBox installed (as of writing: 4.3.22). The server was also configured to run phpVirtualBox to provide a web-based GUI for easier VM management. The VirtualBox user (vinel) is the same user running the Apache HTTP server. A dedicated folder on the NAS server was

created to be the default path for VirtualBox to install virtual machines and store VM images.

Application Features

PHP was used as the primary programming language of the ViNeL application. The following features were implemented using PHP scripts:

1. User Access Control – Each user has an account in ViNeL. Users are only given access to VMs that they have created. Users are grouped into roles and access is restricted by group membership.

2. System Information Dashboard – Upon logging in, users can view the current percent of storage, memory, and CPU in use. If left open, the dashboard refreshes every minute. The dashboard is shown in Figure 6 in the appendix.

3. Launch Instances and Networks – By taking advantages of the Linked Clone (Oracle Corporation, 2004-2015) feature in VirtualBox, users can launch instances or networks depending upon their user role. Users must specify a reservation length for how long they would like to have the VM instance available for use.

4. View Personal Instances and Networks – Users can view instances and networks that they have created and chose to end their reservations early if they are finished using their created instance

5. Add and Delete Users – Elevated users have the ability to upload a CSV file of users to create user accounts. Those accounts can also be removed via the web interface.

6. Import Images and Networks – Elevated users can upload and import images and networks for use by all other members.

7. Delete Images and Networks – Elevated users may delete images and networks if they will never be used again or if there is an error with the configuration that cannot be corrected.

8. Enable and Disable Images - Elevated users may disable images without deleting the files in order to prevent users from accessing the VM. Images may be re-enabled at any time.

Virtual Machine Image Creation

Users are given the option of creating virtual machines on a local machine or in the server using the phpVirtualBox interface. Image creation follows the typical setup process described earlier in the paper. After the image has been configured, it can be uploaded to the server. The

server will automatically import the image into VirtualBox and made it available for use. For network images, system users can supply network names and the system will create an internal DHCP server for a network containing only those virtual machines.

At the initial deployment of ViNeL, a virtual machine image was created for each of the operating systems listed in table 3, contained in the appendix.

These images were created based on operating systems used in the 2014 SECCDQC (SECCDC, 2014), 2015 SECCDC Qualification (SECCDC, 2015), and the 2015 SECCDC Regional (SECCDC, 2015) competitions.

For single instances (lab use), each image was configured to have all updates installed. Network instances (competition use) are not configured with updates. Once the configuration is complete, the image was uploaded via the application website, which saved it to the NAS and made it available for users to deploy.

5. RESULTS

A virtual networking lab was successfully created that met all but one the requirements of the CYBER DEFENSE CLUB. While the ViNeL application is a self-service, platform-independent, free networking working lab, the system cannot currently support 15 lab users at a time. The server hardware would need to be updated or an additional server added to accommodate more users. The system as configured can support 10 simultaneous users with reasonable performance. The competition practice use portion of the application is fully functional and can support all team members practicing at the same time.

6. DISCUSSION

While the implementation of the ViNeL application has provided a solution to the CYBER DEFENSE CLUB problem of the distribution of system configurations, this project does have broader applications. The application can be adapted for academic purposes where the curriculum requires the use of atypical setups and software configurations. Student could use instance of pre-configured machines to complete training on a variety of software product or jump directly into learning new operating systems without the tedious installation process.

In industry, system administrators can use a similar setup to test the compatibility of new software and updates to be deployed across enterprise systems. Software developers can also use the networking lab to test their product across multiple platforms easily and efficiently. While many businesses have similar setups, the one described here can be implemented at very low cost.

7. CONCLUSIONS

The ViNeL application has opened up many possibilities for the Cyber Defense Club. The leaders of the club can now devote more time to research and delve further into security implementations instead of hours of computer configurations. The fact that ViNeL is built on open source product and freely available licenses through DreamSpark will give peace of mind to CYBER DEFENSE CLUB leaders, as there was no need to transfer license information from year to year, nor will money need to be set aside for license purchases each year.

ViNeL can also be used by faculty to advance the level of development and experimentation seen in courses. It can level the computer playing field by insuring each student has the ability to access numerous servers and applications regardless of the physical limitation of their personal computers.

In the future, the following adjustments can be made to the server to provide a better software for users:

1. Save Images – Users can download the current configuration of their VM when their reservation is complete or add the configuration to the list of available images.
2. Custom Launch Scripts – Users can input Bash or Batch scripts to run in the VM during boot to custom their instance from the current configuration.
3. Automated VirtualBox Updates – The system will automatically update VirtualBox Guest Additions on each VM image when a new update becomes available.
4. Detailed Networking – Elevated users have the option to enter more detailed networking information (IP addresses, subnets, etc.) when importing an image.

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Appendices

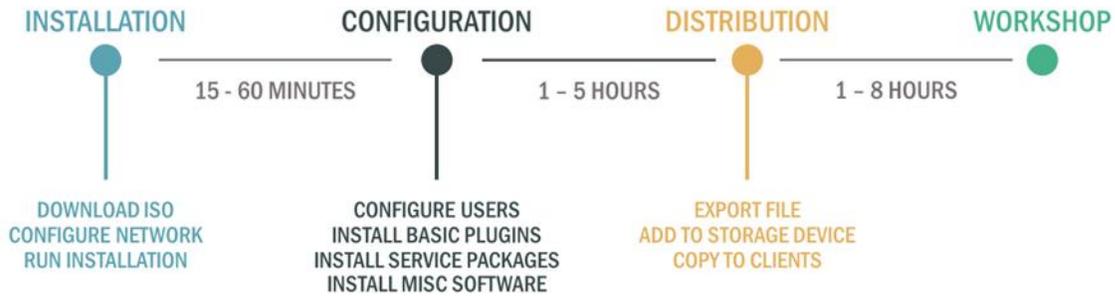


Figure 1 - Lab Setup Time

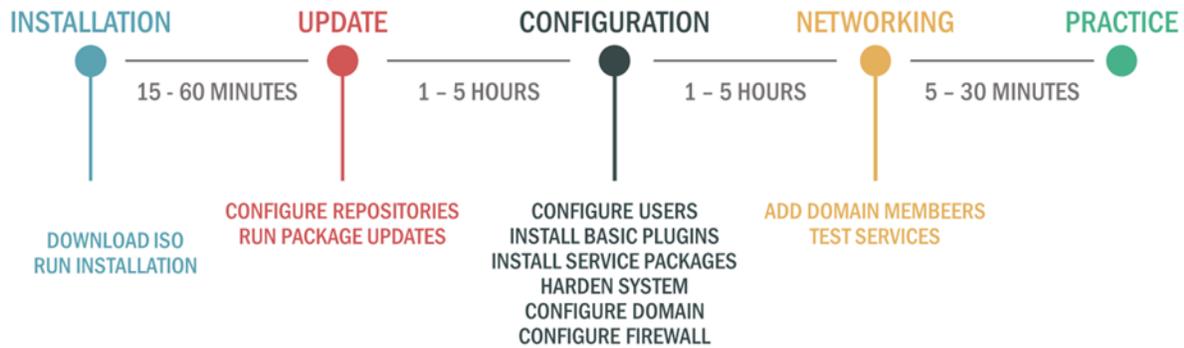


Figure 2 - Competition Practice Setup Timeline

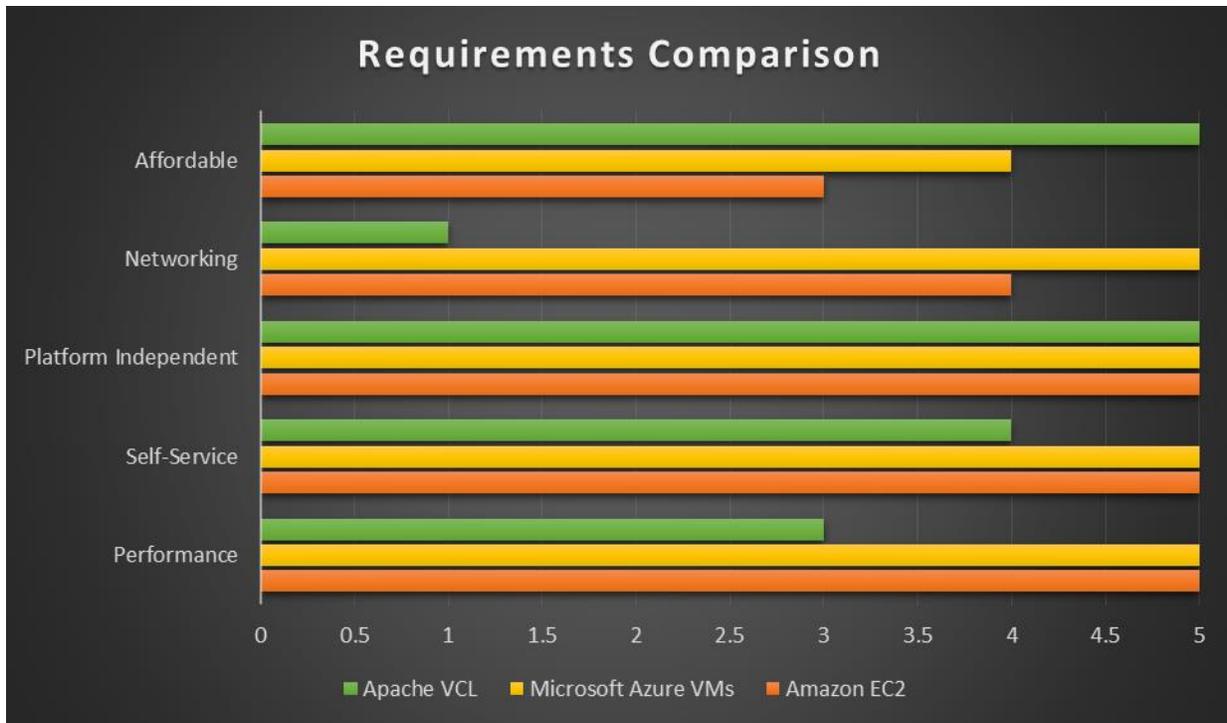


Figure 3 - Requirements Comparison Chart

	Amazon EC2			Microsoft Azure VMs		
	Lab	Competition		Lab	Competition	
Instance Type	t2.small	t2.small	t2.medium	A1	A1	A2
CPU	1	1	2	1	1	2
RAM (GB)	2	2	4	1.75	1.75	3.5
Storage (GB)	15	15	15	40	40	60
Price-per-hour	\$0.03	\$0.03	\$0.05	\$0.08	\$0.08	\$0.15
Hours	4	12	12	4	12	12
Quantity	20	6	1	20	6	1
Additional Charges	\$1.50	\$9.00	\$1.50	N/A	N/A	N/A
Monthly Cost	\$3.58	\$10.87	\$2.12	\$6.16	\$5.54	\$1.82
Total	\$16.57			\$13.52		

Table 1 - Cloud Computing Estimated Monthly Pricing

Feature	Description
Processor	Intel(R) Xeon(R) E5440 @ 2.83GHz
CPU Cores	8
Memory	32 GB (8 x 4 GB)
Ethernet Ports	4 ports, 10/100/1000 Mbps
Internal Storage	120 GB SATA
Removable Media	1 CD/DVD+RW

Table 2 - ViNeL Hardware Specifications

Operating System	Interface Type
Debian 6.0.10	Graphical
Debian 8.0.0	Graphical
Ubuntu Server 8.04.4 LTS	Command Line
Ubuntu Desktop 12.04.5 LTS	Graphical
Ubuntu Server 14.04.2 LTS	Command Line
Metasploitable 2.0.0	Command Line
Kali Linux 1.1.0a	Graphical
pfSense 2.0.1	Command Line
pfSense 2.2	Command Line
Gentoo 11.2	Graphical
OpenSUSE 11.3	Graphical
CentOS 3.9	Command Line
CentOS 6.6	Graphical
VMWare ESXi 5.5	Command Line
Windows XP Professional with SP3	Graphical
Windows Server 2003 R2 Enterprise with SP2	Graphical
Windows Server 2008 Enterprise with SP2	Graphical
Windows Server 2008 R2 Standard with SP1	Graphical
Windows 7 Professional with SP1	Graphical
Windows Server 2012 Standard	Command Line
Windows Server 2012 Standard	Graphical
Windows 10 Technical Preview	Graphical

Table 3 - Virtual Machine Operating Systems

Figure 4 – ViNeL Architectural

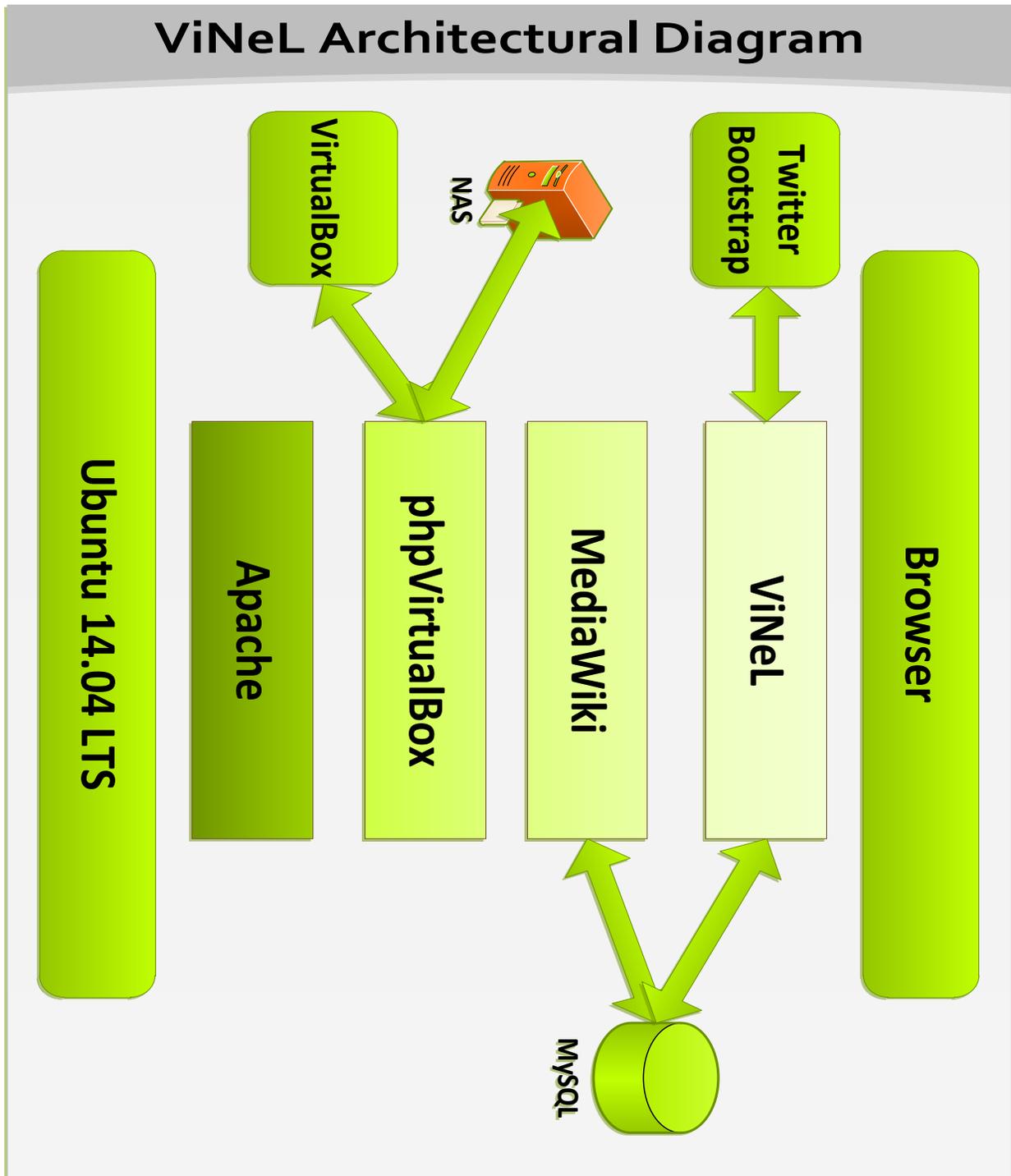


Figure 5 – ViNeL Database

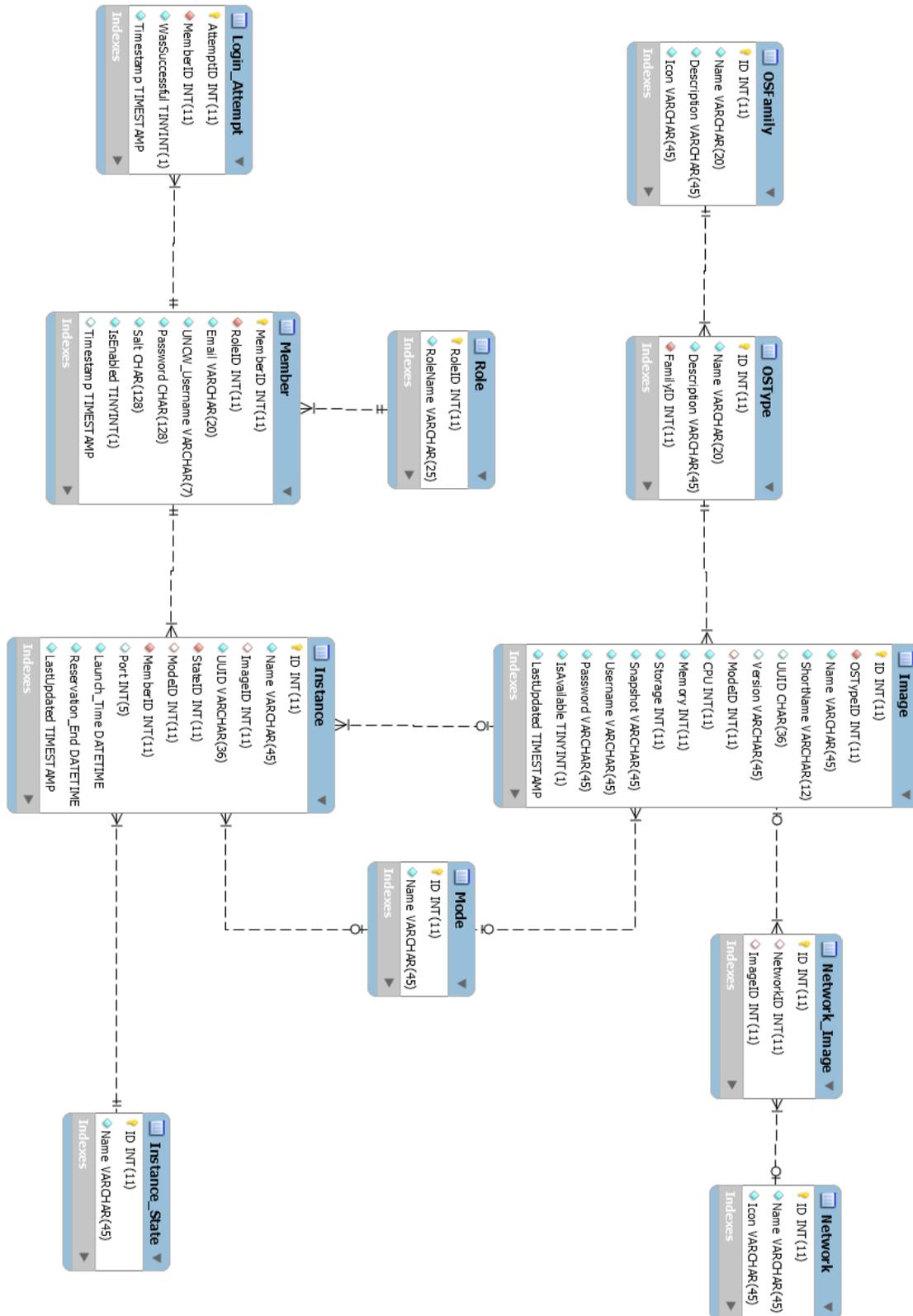


Figure 6 - ViNeL Dashboard

